Thoughts on Multifunction Flight Vehicles

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Outline

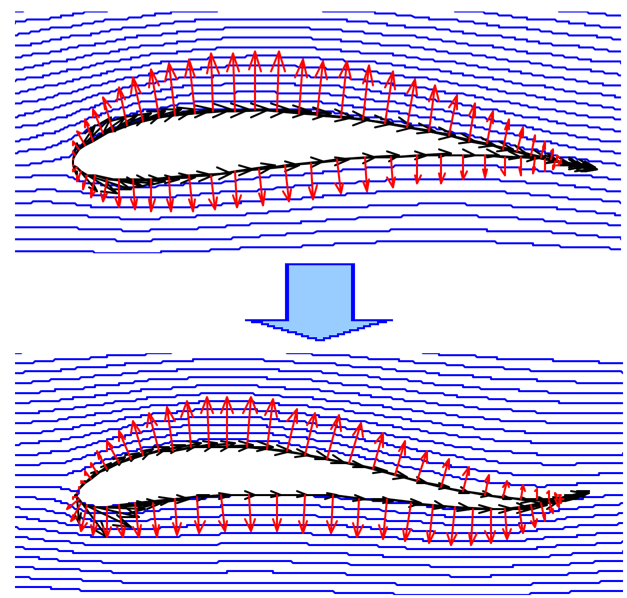
- Quick review of current effort
- Multifunction flight wing configurations
- Thoughts on actuation

Distributed Modeling and Control of Adaptive Wings
Virginia Tech (Robertshaw, Gern, Kapania)

Program Goal:
Determination of minimum control energy required to increase maneuverability of an aileronless UCAV using smart structures and morphing airfoil technology

Objectives:

- Mimic the characteristics of wings with control surfaces
- Determine actuation energy, forces, moments, displacements, and time constants needed for an adaptive wing approach
- Investigate performance and maneuverability improvements of a morphing wing vehicle (no aileron control)

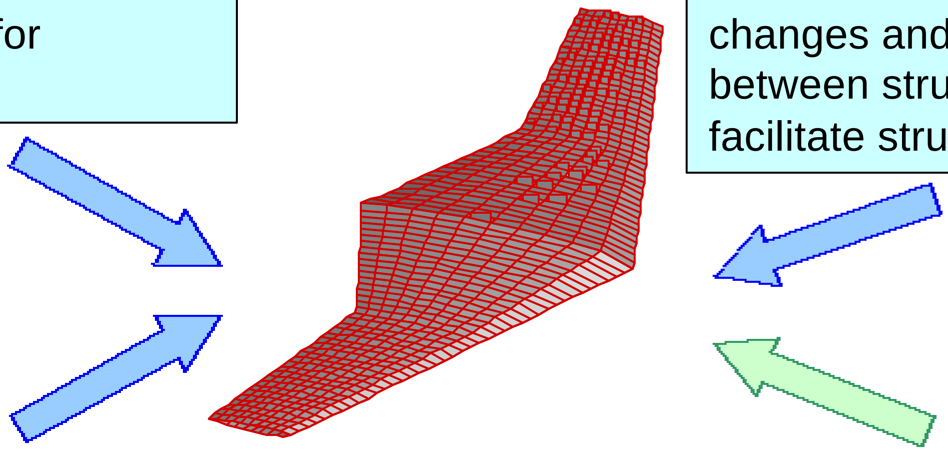


Problem Approach

Determination of force, energy, displacement, and time constant requirements for smart wings:

Task 1: Dynamics & Control
Determine control algorithms to minimize energy input for maneuver control.

Task 2: Aeroservoelasticity
Aeroelastic effects of structural changes and use of energy transfer between structure and airflow to facilitate structural morphing.



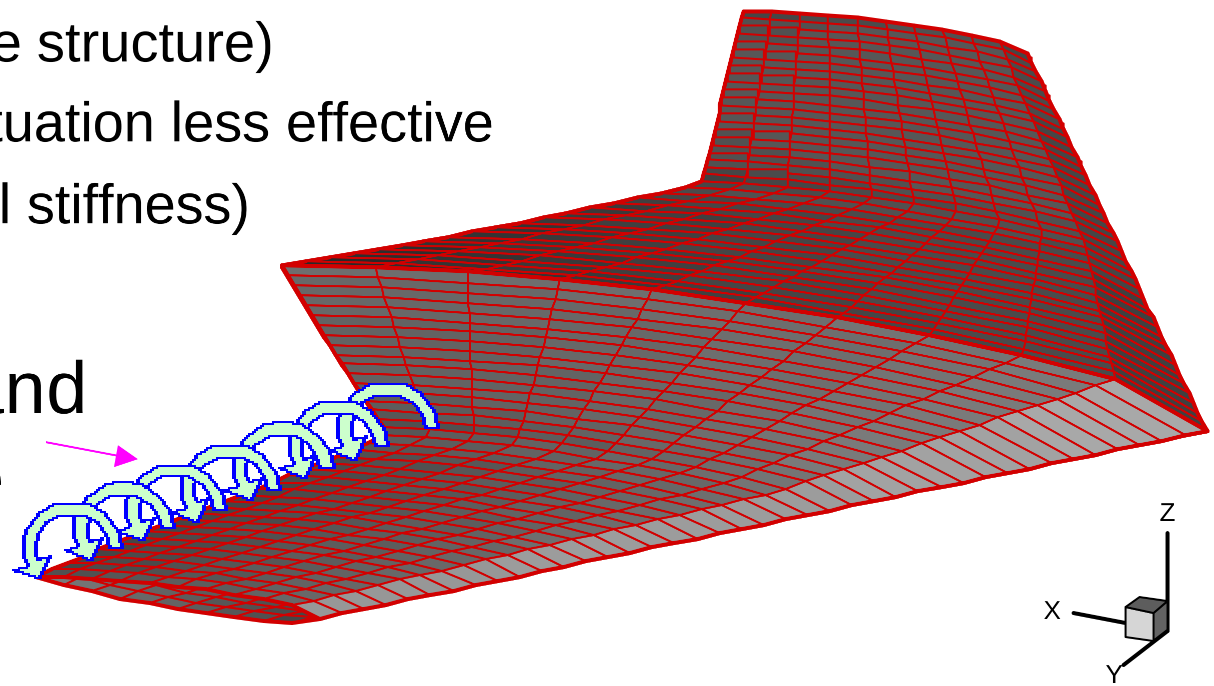
Task 3: Adaptive Structures
Determine the optimum network of sensors and actuators for a given morphing structure to control vehicle maneuver and cruise performance.

Supportive Task: Aerodynamics
Provide expertise in steady and unsteady aerodynamic loads for all tasks by identifying/adapting existing aerodynamic tools.

Smart Wing Actuation

- Constant torque actuation of outboard wing section
  - torque applied close to trailing edge (relatively flexible structure)
  - leading edge actuation less effective (higher structural stiffness)

Need to understand where to actuate



Twist and camber actuation more effective then individual effects

Smart Wing Actuation

- Wing deformation due to torque actuation:

$$\{q\} = [K]^{-1}\{P\}$$

{q} generalized displacement vector

[K] wing stiffness matrix

{P} generalized load vector from actuation forces

- Flexible wing actuation $\rightarrow$ consideration of aerodynamic loads:

$$\left\{P_{tot}\left(q_{dyn}\right)\right\} = \{P_{act}\} + \left\{P_{aero}\left(q_{dyn}\right)\right\}$$

$\{q_{dyn}\}$ dynamic pressure

- Total wing deformation due to actuation and aerodynamic loads:

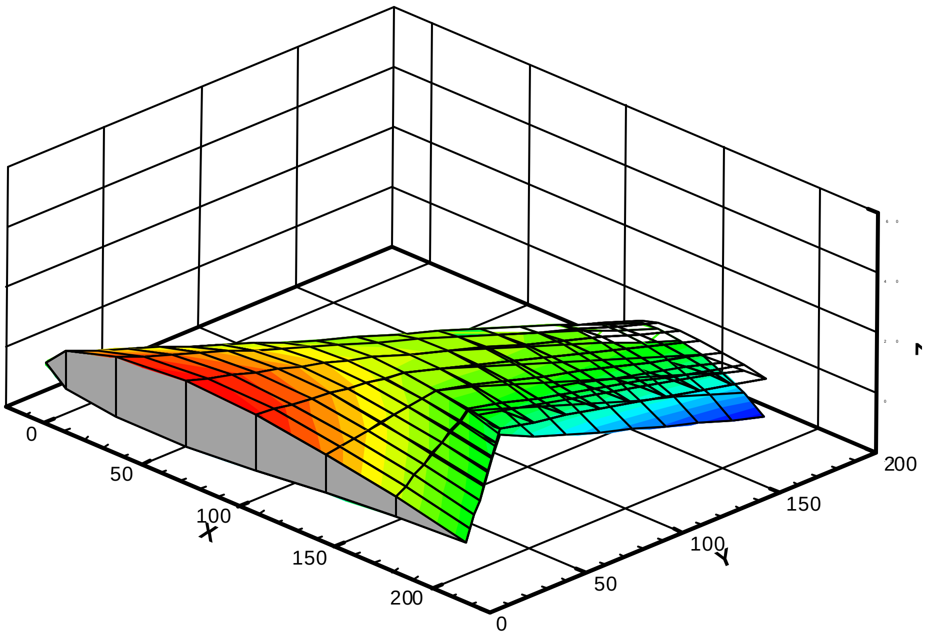
$$\{q\} = [K]^{-1}\left(\{P_{act}\} + \left\{P_{aero}\left(q_{dyn}\right)\right\}\right)$$

Smart Wing Actuation

Constant torque actuation on outboard wing (300 lb-ft/ft)

No aerodynamic loads

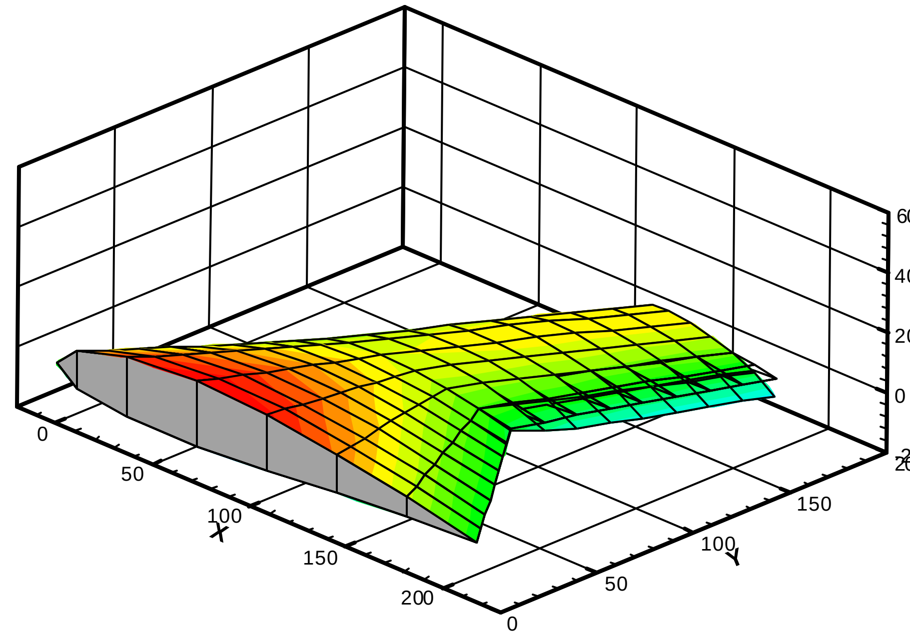
$c_l = 0.482$



Constant torque actuation on outboard wing (300 lb-ft/ft)

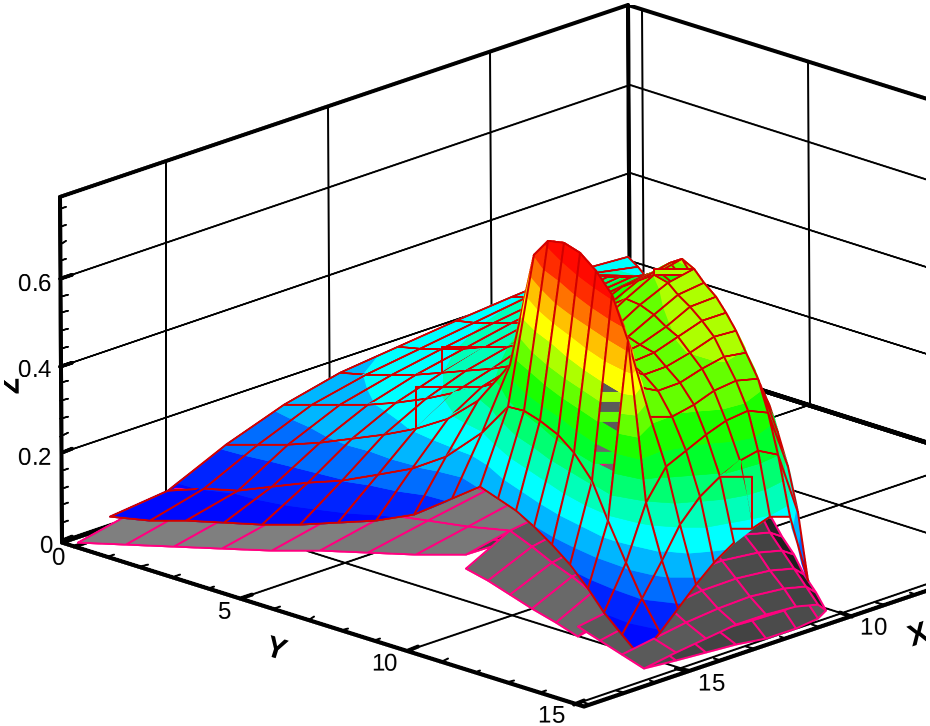
Aerodynamic loads ($5 \cdot q_{ref}$)

$c_L = 0.460$

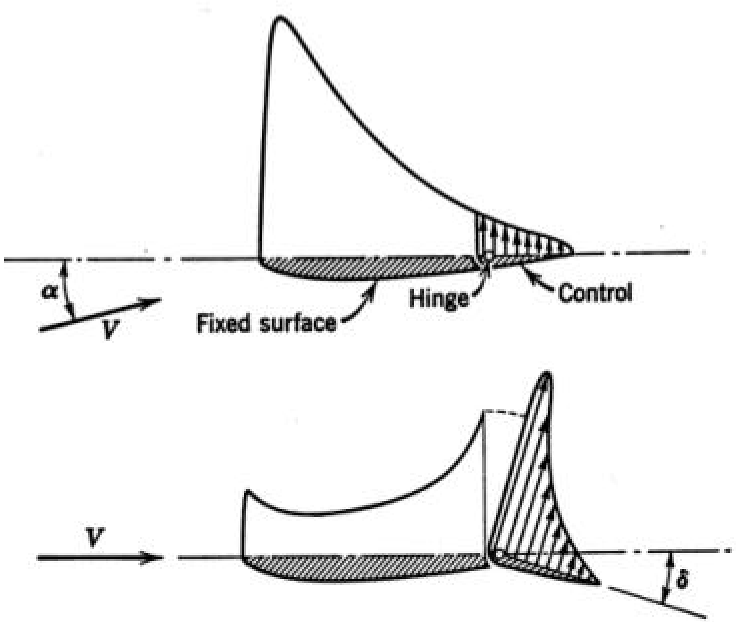


Trailing Edge Flap Performance Evaluation

3d Pressure distribution



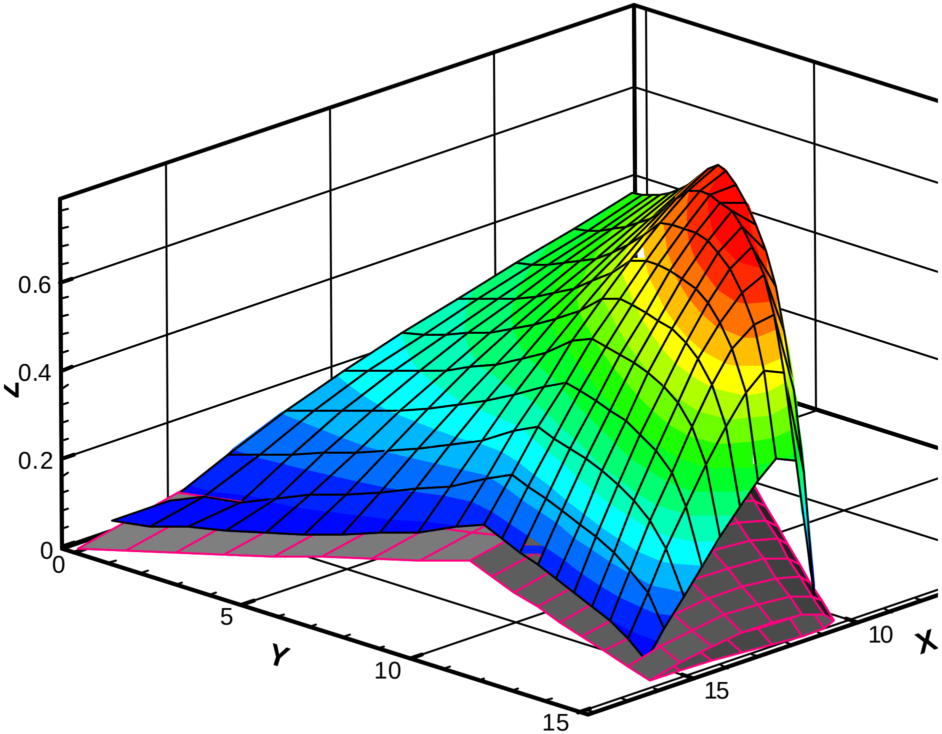
Hinge moment



Actuation energy: $\Delta W_{flap} = \int_0^d M_{flap}(d)dd = \sum_{flap\ panels} \int_0^d \Delta S_{flap\ panel} q \Delta c_p(d) x_{flap\ panel} dd$

Morphing Wing Performance Evaluation

3d Pressure distribution



Wing morphing

- Linear increase of outboard wing camber
- Constant strain actuation of upper and lower skins
- Increase of wing c_L from 0.3 to 0.47
- Equivalent to TE flap 10° down

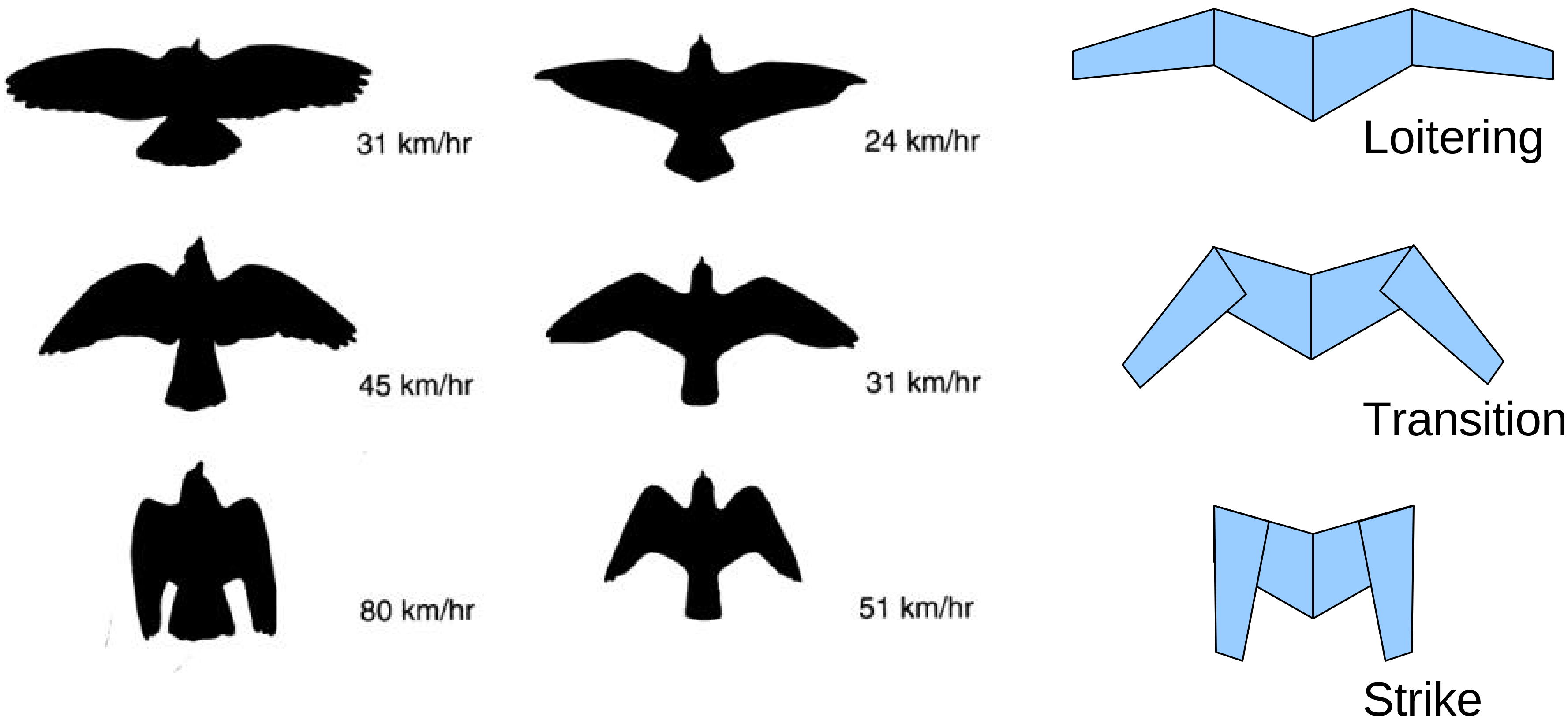
Actuation energy: $$\Delta W = \sum_{panels} \Delta W_{aero} dr = \sum_{panels} \int_{r_1}^{r_2} \Delta S_{panel} q \Delta c_p(r) dr$$

Actuation Energy and Peak Power Draft Calculations

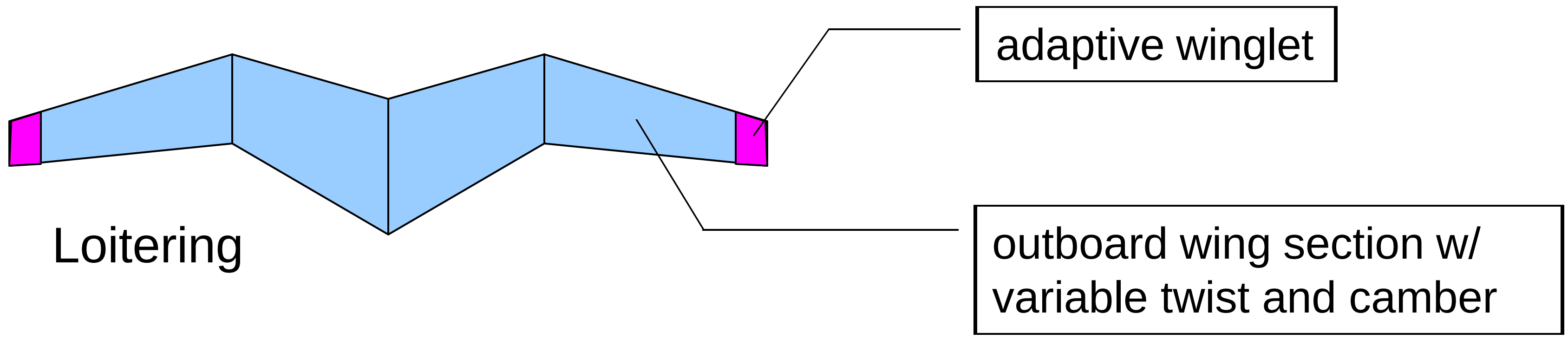
	Trailing edge flap	Morphing wing
$\Delta\chi_A$	0.17 (0.3 to 0.47)	0.17 (0.3 to 0.47)
Actuation	Flap10º down	Increased outboard wing camber (eq. flap10º down)
Actuation energy	136.99 ft-lbf (185.732 J)	423.13 ft-lbf (573.687 J)
Peak power (based on 90º/sec flap rotation)	1232.90 ft-lbf/sec (2.24 HP)	3808.17 ft-lbf/sec (6.92 HP)
Hinge moment	1302.7 ft-lbf (15632 in-lbf)	N/A

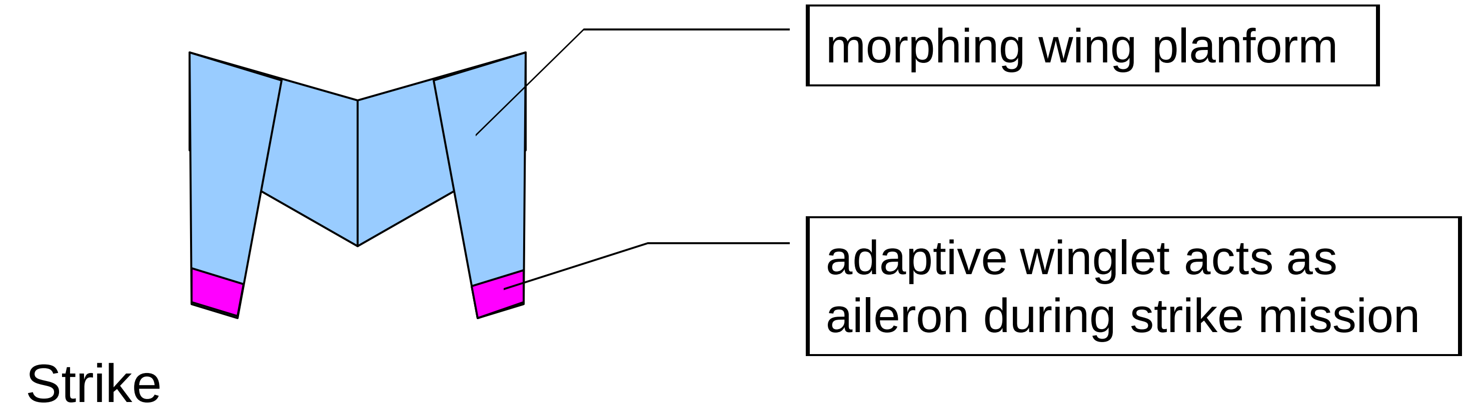
Multimission Vehicle inspired by nature

Pigeon | Falcon | Morph-Eagle



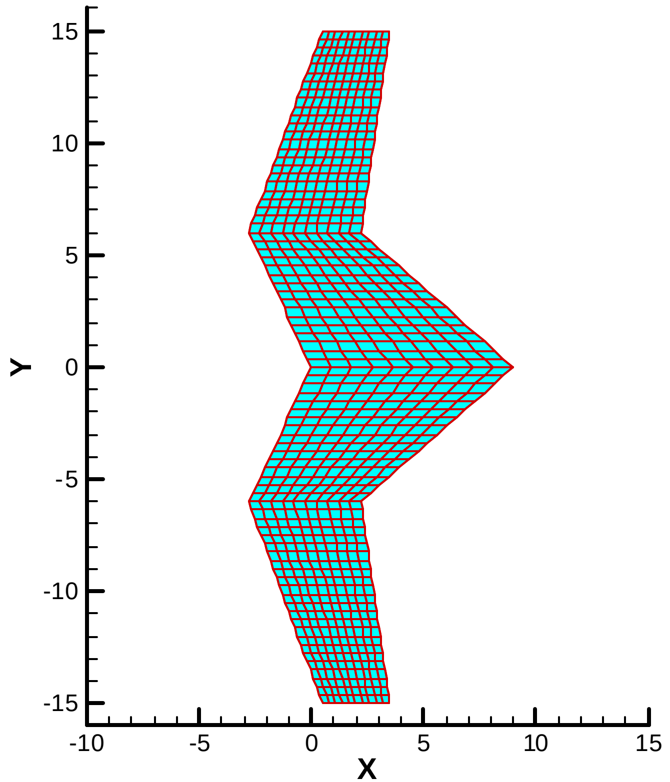
Multimission Vehicle



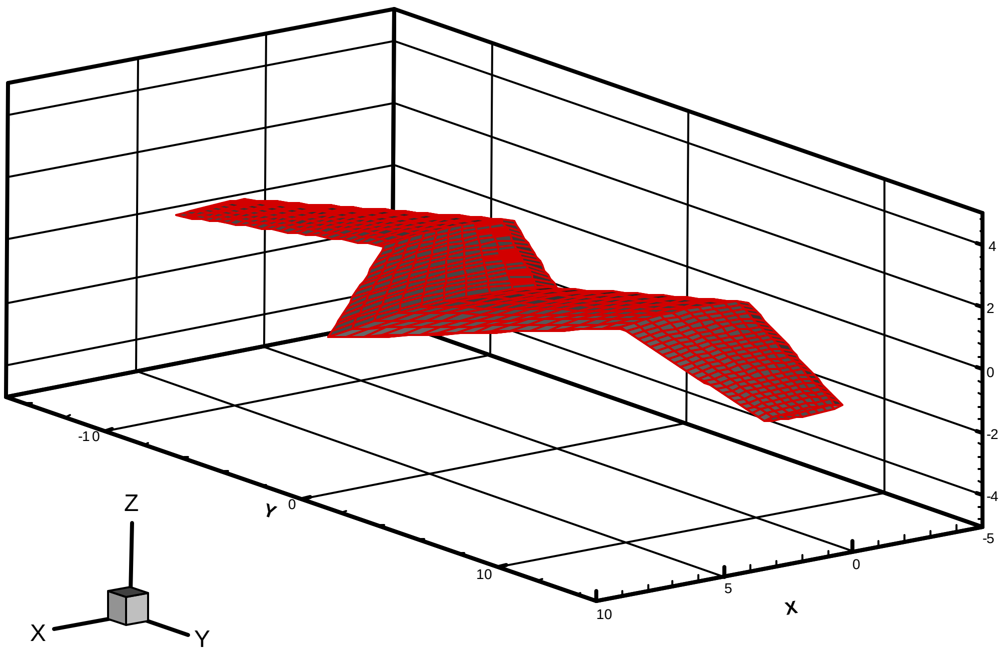


Multimission Vehicle model being used

Wing Planform

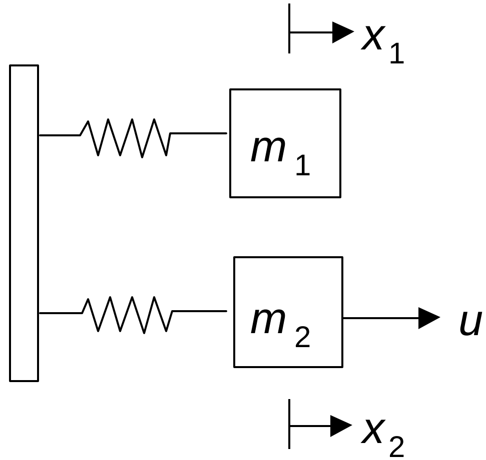


3D View

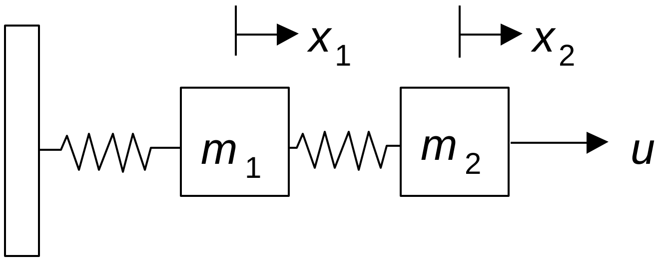


Lessons learned from Structural Control

Controllability:



An example of an uncontrollable mechanical system



An example of a controllable mechanical system

- Unobservable if $y = x_2$
- Becomes controllable if u is also applied at x_1
- Uncontrollable for u at x_2

Controllability Measure

- The controllability increase obtained by integrating the active member into the structure can be illustrated by calculating the gross measure of controllability
- Adding the active member into the control system significantly increases the controllability of the torsional modes for a marginal (0.1%) increase in power.

	Gross Controllability	
Mode	Slewing Actuator	+ Active Member
1st torsional	8.62	109.55
1st bending	155.16	156.42
2nd torsional	1.11	39.81
1st plate	17.28	54.31
2nd bending	80.29	91.61

Actuator Location Makes a Critical Difference

Rigid body actuator 120 watts

PZT Actuators 0.3 watts

30% increase in performance

- Dynamics are rigid body plus flexible modes
- Rigid body actuator has poor control authority over torsional modes
- Results of using controllability are improved performance for little cost from a small actuator in exactly the right spot
- Placement of actuators is key and determined by dynamics

What are the steps to get there? - an actuator view

- Move with out fighting internal strain
- Go with the flow (use aero forces)
- Determine how much motion is needed?
- Determine energy required to go from A to B to A
- Energy (force, stroke, time constant) and location are the key issues to be sorted out before proceeding.